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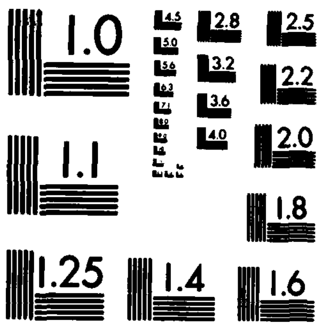

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Radiofrequency and Microwave Radiation

K. J. KING

Health Physics Staff

August 9, 1984

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The results of a literature review on radiofrequency (RF) and microwave radiation safety are given. This review highlights the most recent information on sources and applications of RF and microwave radiation, biological effects, RF and microwave radiation protection standards, and a brief overview of the Health Physics Staff's non-ionizing radiation safety program.

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RADIOFREQUENCY AND MICROWAVE RADIATION

INTRODUCTION

The Naval Research Laboratory is recognized for its outstanding accomplishments in radiofrequency (RF) and microwave research and has remained a leader in this field since the advent of radar. In support of this effort, the Laboratory uses a variety of commercially made and in-house fabricated RF and microwave equipment which produces radiation having a wide spectrum of frequencies and power levels. Although the development and applications of these sources of radiation provide significant benefits to the Navy and mankind, they also constitute hazards to personnel through uncontrolled and excessive emissions of radiation.

The Health Physics Staff was given the responsibility for RF and microwave radiation safety in 1969. Since that time, the Staff has steadily upgraded its program by remaining current with the most recent instrumentation, computational techniques, new regulations, and experimental results on biological effects.

The purpose of this report is to present some of the latest information on:

(1) Sources and applications of RF and microwaves, including possible exposure levels;

(2) Biological effects;

(3) RF and microwave radiation protection standards; and

(4) RF and microwave radiation safety at NRL.

SOURCES AND APPLICATIONS

In order to talk about sources of RF and microwave radiation, we must first get some idea of what frequencies are considered to be in the RF region and what frequencies are considered to be microwaves. The distinction between the two is not clearly defined in the literature, but, for the purposes of this report, the definition stated in the World Health Organization Criteria 16, entitled "Radiofrequency and Microwaves", 1981, will be used. This report defines the radiofrequency region as being between 100 kHz and 300 mHz, and the microwave region as being from 300 mHz to 300 GHz.

Sources of RF and microwave radiation fall into two main categories; naturally occurring and man-made. Like the background from ionizing radiation due to cosmic rays and naturally occurring radioactivity in the earth, there is also a constant background from non-ionizing RF and microwave radiation. This background is partly due to extraterrestrial sources, with the greatest

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amount coming from solar emissions such as solar flares and sunspot activity. Typically, the integrated flux of radiation from 300 mHz to 300 GHz is approximately 1.4×10^{-5} $\mu W/cm^2$ for a quiet sun increasing to as high as 10^{-3} $\mu W/cm^2$ during periods of high solar activity. Other background sources include the earth, which emits an integrated flux up to 300 GHz of approximately 0.3 $\mu W/cm^2$ and even the human body which emits approximately 0.3 $\mu W/cm^2$ of thermal radiation integrated over the range of 10 KHz to 300 GHz. These background radiation levels are very low, but the exposure level to man is rising due to the increased use of man-made RF and microwave producing devices. The four main types of man-made devices include: power grid tubes, linear-field devices (Klystrons); cross-field devices (magnetrons, amplitrons); and solid-state devices. These devices are used to produce RF and microwave radiation which have found uses in such diverse areas as broadcasting and communications, radar, heating and curing of materials for industrial purposes, and a variety of medical diagnostic and therapeutic applications. Microwave ovens for heating and cooking of foods are widely used in restaurants and carry-outs as well as becoming a common appliance for cooking in private homes. These, and many other modern applications, have increased the exposure of occupational workers, as well as the general public to RF and microwave radiation.

Broadcasting and Communications

The greatest application of RF and microwave radiation is in the broadcasting and communications industry. Because of the number of commercial broadcasting operations, specific frequency bands have been assigned for radio and television transmissions as shown in Table 1. The major exposures to the general population come from these sources. Radiation transmitted from broadcasting towers can have an input power in megawatts with radiating powers in tens of kilowatts. Measurements made in a recent survey of 15 major U.S. cities showed that 99% of the general public is exposed to < 0.1 $\mu W/cm^2$ in the frequency range of 54 - 900 mHz. Sources outside this frequency range do not contribute significantly to the exposure level.

TABLE 1

Frequency Band (MHz)	Application	Tower Height (m)	Maximum ERP (kW)	Field Intensity (mV/m)	Power Density ($\mu W/cm^2$)
0.535-1.605	AM Radio				
54-88	VHF TV ch. 2-6	305	100	807	1.73
88-108	FM Radio	152	100	1023	2.78
174-216	VHF TV ch. 7-13	305	316	191	0.1
470-890	UHF TV	305	5000	380	0.38

Mobile Communications Devices

There has been a recent surge in the popularity of personal communications devices such as citizens band radios and hand-held walkie-talkies. Telemetry devices used in tracking are also finding increased use

in animal studies involving migratory habits, hibernation, and endangered species research. Table 2 lists the typical operating frequencies and maximum permitted power outputs for each of these devices:

TABLE 2

Device	Frequencies	Maximum Permitted Power
CB	30 - 54 mHz VHF	100 W
	132 - 174 mHz VHF	"
	403 - 512 mHz UHF	"
Walkie-Talkies	30 - 512 mHz	6 W
Telemetry Transmitters	75 - 160 mHz	100 W

Radiation fields from these instruments are very difficult to measure accurately because of the constant changes in geometry of nearby objects, intermittent operation, and because most measurements are made in the near field region where the power density patterns are very complex.

Satellite Communications

Satellite communications antennas are usually located in remote areas where human population is very low. The microwave radiation is generally directed into a circular antenna and the resulting beam is very well defined. Safety interlocks are used to keep the antenna from radiating below the horizon or into populated areas. Typical radiation frequencies fall into the range of 2 - 8 GHz with effective radiated powers in excess of 1 Megawatt. Antennas having much higher powers are being developed; in fact, it was reported that in 1974 the U.S. had 20 nonpulsed unclassified sources with average radiated powers ranging from 5 to 31.6 GWatts with one source as high as 3.2 Terawatts.

Radars (High and Low Power)

High-powered radars are generally tracking and acquisition type radars which typically operate at frequencies between 1 - 9 GHz at power levels of 150 KW. Some of the most powerful unclassified pulsed radar systems have average effective radiated powers of 8.7 to 840 megawatts and peak effective radiated powers ranging from 35.4 GWatts to 2.8 TWatts. These radars either have rotational antennas for acquisition or non-rotational antennas for tracking, and are generally located in remote areas near airports or military bases where personnel can be exposed to side-lobe or secondary radiation.

Low-powered radars are generally weather radars located in the nose of aircraft covered by a radome. They normally operate at frequencies of 5.4 or 9.375 GHz at power levels from 20 - 100 Kw. Approximate power densitites of 13.5 mW/cm^2 occur at the radome, falling off to less than 3 mW/cm^2 at a distance of 1 meter. Several measurements made in the cockpits of planes having these type radars showed no radiation levels greater than 0.2 mW/cm^2.

Traffic speed measuring radars operate at a frequency of 10.525 GHz with power levels approximately 0.1 Watt. The maximum power density measured at the antenna surface varies between 170 - 400 $\mu W/cm^2$.

Heating

Microwaves used for heating have found many applications in industry, commerce, and the home. The frequencies most often used are 915 or 2450 mHz. The most popular use is microwave ovens used for cooking food. Ovens manufactured for home use are typically low power with an average power of about 600 Watts, while some industrial heating ovens exceed 1.5 kW. Since microwave ovens are sold for home use, the allowable radiation leakage when the oven leaves the factory is strictly regulated by the U.S. Department of Health and Human Services, Food and Drug Administration. An oven leaking at the allowed limit of 5 mW/cm^2 at 5 cm from the surface will have a power density reading of less than 0.5 mW/cm^2 at 0.3 meters and approximately 10 $\mu W/cm^2$ at 1.0 meter.

Dielectric (RF) Heaters

Dielectric heaters are used in industry to heat, melt, or cure materials such as plastic, glue, or rubber. They typically operate at frequencies between 3 - 70 mHz with a few units operating between 300 - 400 mHz. These devices have caused a great deal of concern because of poor design and inadequate shielding. Recent surveys done in Canada near devices operating between 4 - 51 mHz at power levels from 0.5 - 90 kW have shown operator exposures to be greater than 10 mW/cm^2 for several types of these units. Of particular concern are operators working near units operating at or near the region of human resonant absorption frequencies (60 - 100 mHz), where they can absorb a great deal more energy than would be possible at frequencies outside this range.

Medical Applications

Diagnostic medical applications are mainly in the research stage and generally involve the use of low-power sources. Techniques to measure changes in fluid accumulation in the lungs, microwave radiometry to measure "hot spots" such as malignant lumps in the breasts, and a non-invasive electromagnetic flow meter to monitor the flow of blood in humans, are all

examples of work being done in the field of medical diagnostics using RF and microwave radiation.

Therapeutic applications of RF and microwave radiation using high-power sources have recently been used for the treatment of malignant tumors. This type of treatment takes advantage of the fact that malignant cells are much more sensitive to heat than normal cells and, in addition, many tumors above 1 cm in diameter have poorer blood supplies; thus making them unable to dissipate heat efficiently. The frequencies most commonly used include the radio frequencies of 13.56 and 27.12 mHz, and the microwave frequencies of 434, 915, and 2450 mHz.

Diathermy treatments are an example of low-powered therapeutic applications of RF and microwave radiation. This treatment is used to generate heat in body tissues for the treatment of arthritis, muscle spasms, etc., without excessive heating of surface or subcutaneous tissue. Frequencies from 10 - 100 mHz are used in the radiofrequency range with 27.12 mHz being the most commonly used. Microwave frequencies from 300 - 100,000 mHz are also used with 2450 mHz being the most common frequency used. Leakage radiation, especially in the older units, exposed operators at the control console to up to 1.3 mW/cm^2 during treatment. Radiation from the applicator to 5 cm away from a phantom could be as high as 44 mW/cm^2. New designs in applicators, better shielding of cables, and education of the operators as to where to stand during therapy, could offer a greater degree of safety.

Electrosurgical Devices

Electrosurgical devices are used for cutting and cauterizing tissue in almost every hospital, doctors' office, and clinic in the U.S. They operate at frequencies of 0.2 to 2.4 mHz continuous wave when used for cutting, and in an amplitude modulation mode when coagulation is desired. Measurements made at 16 cm from the probe gave plane wave power density readings of up to 265 mW/cm^2 at normal power. These units require a great deal of care when in use, since they interfere with patient monitoring devices, life support systems, and are a potential radiation exposure hazard to the operator.

Video Display Units

Video display units have been much maligned over the years and have been blamed for all sorts of problems ranging from miscarriages to cataracts. Surveys conducted by the National Institute of Occupational Safety and Health (NIOSH) have indicated that there is no microwave leakage from these units and therefore no adverse health effects are to be expected.

These applications represent a few of the wide range of uses RF and microwave sources have found in today's environment. The exposures to

the general public are extremely low and thus are not expected to cause any long-term health effects. There are some occupational exposures which could cause a problem, but proper monitoring and education of the operators can minimize the potential exposures, thus reducing the chances for physical injuries to occur.

BIOLOGICAL EFFECTS

Research on the biological effects of RF and microwave radiation has increased greatly since World War II. Several approaches are used to investigate the possibility of harmful effects caused by exposure to non-ionizing radiation. One is the direct approach, by studying the effects of exposure on laboratory animals. This approach is sometimes questioned since it is difficult to extrapolate effects observed in animals to what might be expected to happen in humans under the same circumstances. The second approach is to make an epidemiological study using large groups of subjects which have been exposed to RF and/or microwave radiation. This is done by comparing such things as mortality rates, morbidity, and reproductive performance of the exposed group to that of another large group which was not exposed to radiation. The main problem encountered with this type of study is correlating the observed effects with exposure levels.

Radiation exposures to humans are generally broken down into three levels of intensity:

1. High-Power Density -- levels greater than 10 mW/cm^2 where distinct thermal effects are observed.

2. Medium Power Density -- levels from 1 - 10 mW/cm^2 where weak but noticeable thermal effects exist; and

3. Low-Power Density -- levels below 1.0 mW/cm^2 where thermal effects are improbable.

Although very little actual experimental data on humans exist, it is generally believed that from the few observations which have been made, no permanent effects occur below exposures of 10 mW/cm^2. Once the radiation field is eliminated, whatever effects had occurred quickly disappeared with no permanent damage. Several of the most important biological systems have been studied in detail and will be briefly covered.

The Eye

The eye is generally considered the most critical organ in the field of non-ionizing radiation protection. The main reason is the susceptibility of the lens to damage caused by the heat of microwave absorption.

This problem is more critical in the eye because of the lower supply of blood vessels to this organ. Experimental data on cataract formation has come from exposing animals such as rabbits, monkeys, dogs, and cats. The frequencies most often studied include 0.9, 2.45, 3.2, and 9.0 GHz, both continuous wave (CW) and pulsed. It is apparent, but not understood, from the results of these studies that pulsed fields are a stronger cataract-producing mechanism than CW fields at the same average power flux densities.

The incidence of cataracts in humans that have had occupational exposures to microwaves is not statistically different from that in groups of workers not occupationally exposed. In the few cases of confirmed cataract formation due to microwave exposures, the power density levels exceeded 100 mW/cm^2 and were cited as high as 1000 mW/cm^2. One interesting note from studies on experimentally induced cataracts in animals and accidentally induced cataracts in humans is that there are no distinguishable differences between those which are naturally produced and those which are caused by microwave exposure.

Cardiovascular System

Investigators have noted changes in the cardiovascular system such as bradycardia (slowness of heat beat, less than 60 bpm), delayed auricular and ventricular conduction, decreased blood pressure, ECG alterations in workers exposed to levels of RF and microwave radiation which were low enough to not produce thermal effects. These changes are reversible and no permanent vascular damage has been reported.

Hematopoietic (Blood Forming) Effects

Several reports on effects to the blood and blood forming organs from exposure to RF and/or microwave radiation are inconsistent. A number of investigators state that there are no effects from chronic or acute exposures, while others have observed some changes. The observed effects are dependent on the intensity, time of exposure, and the amount of induced hyperthermia. There appears to be no permanent damage once the source is removed.

Gonads

RF and/or microwave radiation exposure of the testes has been studied extensively. The heat sensitivity of this organ is well known, which makes it especially sensitive to this type of radiation. Effects such as decreased spermatogenesis occur at power density levels of greater than 10 mW/cm^2. No permanent damage occurs and normal function is restored within a few days after exposures have been terminated.

Growth and Development

Some observed effects of embryological development and postnatal growth have been suggested after exposures to certain frequencies, duration, and power levels. In almost all instances, these effects were caused by excessive heat generated by the radiation. A review of the available data indicates, however, that no serious effects are to be expected at power densities below 10 mW/cm^2 under normal exposure conditions.

Carcinogenesis

There have been no reported cases of cancer resulting from exposure to RF or microwave radiation, either experimentally or suspected, in occupational medical surveillance examinations. In addition, epidimological studies have shown no excess of any forms of cancer to date that can be linked to non-ionizing radiation exposure.

In summary, experiments done on laboratory animals have shown that there are definite effects in terms of functional disturbances and/or structural alterations, on organ and organ systems exposed to RF and microwave radiation. In all cases where exposures were in the low to medium power range, there were no observable biological effects. Even at higher power levels, the effects produced during exposures of short duration completely disappeared after the irradiation was discontinued. There is, however, a potential for injury since the trend in instrumentation is toward more efficient and higher power transmissions. The potential for injury was recognized shortly after radar was developed and prompted several U.S. groups, as well as other countries, to adopt RF and microwave protection standards in order to reduce the possibility of injuries to occupational workers and the general public.

RF AND MICROWAVE PROTECTION STANDARDS

The rational used for establishing radiation protection standards takes into consideration two basic groups of people. The first group consists of healthy adults, exposed under normal working conditions, who are aware of the risks and are periodically checked by some type of occupational medical surveillance. The second group includes the general population comprised of individuals of all ages and consisting of a wide spectrum of health related conditions. Standards covering occupational workers and equipment emission standards set for products, mainly microwave cooking ovens, are continually being reviewed and revised by a number of regulatory groups.

Occupational Workers Standards

In the early 1950's, the United States established standards for RF and microwave radiation exposure at 10 mW/cm^2. This limit was frequency

independent and included a built-in safety factor based on the information available at that time. This safety factor was based on the assumption that biological damage probably did not occur at exposure levels below 100 mW/cm^2; therefore, a reduction by a factor of ten was introduced which established the limit at 10 mW/cm^2. This limit was also adopted in 1966 by the American National Standards Institute (ANSI) which is a voluntary group with members from government, industry, various associations, and the academic community. ANSI set the limit of exposure at 10 mW/cm^2 as averaged over a 6-minute period for frequencies from 10 mHz to 100 GHz. These standards remained unchanged until September of 1982 when ANSI released its updated version which expands the range of frequencies covered from 300 kHz to 100 GHz and sets the exposure (Table 3) limits as a function of the frequency.

TABLE 3

RADIOFREQUENCY PROTECTION GUIDES

1	2	3	4
Frequency Range (MHz)	E^2 (V^2/m^2)	H^2 (A^2/m^2)	Power Density (mW/cm^2)
0.3 -- 3	400,000	2.5	100
3 -- 30	4,000 (900/f^2)	0.025 (900/f^2)	900/f^2
30 -- 300	4,000	0.025	1.0
300 -- 1,500	4,000 (f/300)	0.025 (f/300)	f/300
1,500 -- 100,000	20,000	0.125	5.0

Note: f = frequency (MHz).

This new standard is based on the most recent review of the literature and, although there have been no verified reports of injury or adverse effects from exposures under the old guidelines, it was felt that new limits should be set based on the now well established findings of the frequency-dependent human body resonances. These studies revealed that at frequencies near 70 mHz for standard man, there is an approximate seven-fold increase in absorption relative to that at 2450 mHz. Therefore, the frequencies across the range of human body sizes from small infants to large adults are adjusted to account for this phenomena. Exempted from this standard are hand-held walkie-talkies, citizen's band radios, land-mobile, and marine transmitters.

Equipment Emission Standards (Microwave Ovens)

On 6 October 1970, the United States Department of Health and Human Services, Food and Drug Administration, published, as a final rule, (21 Code of Federal Regulations 1030.10) performance standards for the manufacture and

sale of microwave cooking ovens. This standard contains the following conditions:

- o Microwave emission shall not exceed 1 mW/cm^2 at 5 cm or more from the external surface of the oven prior to acquisition by the purchaser and shall not exceed 5 mW/cm^2 at any time thereafter.

- o Microwave ovens shall have two interlocks, one of which must be concealed.

- o Failure of a single mechanical or electrical component shall not cause all safety interlocks to fail.

- o Service adjustments or service procedures shall not cause safety interlocks to become inoperative or the microwave emission to exceed allowable limits.

- o Insertion of objects into the oven cavity shall not result in microwave emission in excess of the limits through reradiation.

In addition to the ANSI standards and the federal regulations covering occupational exposure limits and those for the manufacture and safe use of microwave ovens, the Health Physics Staff must also follow the objectives set forth in a number of Navy instructions.

RF and Microwave Safety Program at NRL

The Health Physics Staff has established an RF and microwave safety program designed to meet the requirements stated in several Navy instructions. Listed below are the current instructions and the objectives each one is designed to accomplish:

- o NAVMED Instruction 6470.13A of 20 January 1977, "Microwave and Radiofrequency Health Hazards":

  - -- Calls attention to the possible health hazards associated with exposure to electromagnetic fields of 10 mHz to 100 GHz.

  - -- Specifies maximum exposure levels in terms of external field quantities.

  - -- Provides guidance for medical surveillance.

  - -- Specifies reporting requirements of microwave overexposure incidents.

- o NAVMED Instruction 6470.16A of 31 July 1980, "Microwave Ovens: Surveys for Hazard";

  - -- Outlines the proper instrumentation to use.

  - -- Provides for the calibration of microwave survey instruments.

-- Reviews survey procedures and specifies how often ovens should be checked.

o NRLINST 5100.14C of 23 September 1983, "Radiofrequency and Microwave Safety Program":

-- Combines the requirements of NAVMED Instructions 6470.13A and 6470.16A.

-- Includes the more restrictive exposure limits from the new ANSI standard.

In a continuing effort to keep personnel exposure levels to a minimum, the Health Physics Staff evaluates experimental, as well as operational setups, either by an on-site survey or computer analysis. On-site surveys are made with state-of-the-art survey instrumentation which covers a broad range of frequencies from 10 mHz to 40 GHz. Where on-site surveys are not practical, such as with large antenna arrays, computer analysis of near-field and far-field beam densities of circular and rectangular antennas are done. In addition, quarterly surveys are performed on all the microwave ovens in use throughout the Laboratory.

To fulfill the requirements of the medical surveillance program, the Health Physics Staff is identifying on a continuing basis, those individuals who require physical and eye examinations. A list is periodically supplied to the Medical Clinic where the examinations are scheduled and performed.

CONCLUSION

It is obvious that the use of RF and microwave producing equipment is going to grow in the future. This will mean that the general public, as well as occupational workers, will have a greater potential for exposures. There is very little evidence that serious injuries have been caused by exposures of short duration to RF and/or microwave radiation. There is, however, little or no experimental evidence as to what effects long term exposures may cause, or what subtle behavorial effects occur at low average power densities. The recent trend in exposure guides reflect the latest experimental evidence which reveals the human body resonance effects. Future studies may make it necessary to reduce the allowable limits even further; therefore, the philosophy of the Health Physics Staff's RF and microwave safety program is to keep exposures to as low as reasonably achievable without interfering with the investigator's ability to accomplish the objectives of the experiment.

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